



**Federal Aviation  
Administration**

DOT/FAA/AM-05/21  
Office of Aerospace Medicine  
Washington, DC 20591

# Medical Surveillance Programs for Aircraft Maintenance Personnel Performing Nondestructive Inspection and Testing

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November 2005

Final Report

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**Technical Report Documentation Page**

1. Report No. <p align="center">DOT/FAA/AM-05/21</p>		2. Government Accession No.		3. Recipient's Catalog No.	
4. Title and Subtitle <p>Medical Surveillance Programs for Aircraft Maintenance Personnel Performing Nondestructive Inspection and Testing</p>				5. Report Date <p align="center">November 2005</p>	
				6. Performing Organization Code	
7. Author(s) <p>Nakagawara VB,<sup>1</sup> Montgomery RW,<sup>1</sup> Good GW<sup>2</sup></p>				8. Performing Organization Report No.	
9. Performing Organization Name and Address <p><sup>1</sup>FAA Civil Aerospace Medical Institute P.O. Box 25082 Oklahoma City, OK 73125</p> <p><sup>2</sup>The Ohio State University Columbus, OH 43210</p>				10. Work Unit No. (TRAIS)	
				11. Contract or Grant No.	
12. Sponsoring Agency name and Address <p>Office of Aerospace Medicine Federal Aviation Administration 800 Independence Ave, S.W. Washington, DC 20591</p>				13. Type of Report and Period Covered	
				14. Sponsoring Agency Code	
15. Supplemental Notes					
16. Abstract <p><b>INTRODUCTION:</b> Visual inspection and nondestructive inspection and testing (NDI/NDT) are performed routinely to ensure that aircraft are maintained in safe operating condition. Inspectors must make critical judgments about the condition of aircraft and aircraft components using their eyes, basic visual aids (magnifiers, mirrors, and flashlights), and complicated NDI/NDT techniques to detect anomalies. Failure to detect observable defects has been implicated in several aviation accidents. This study examines the medical surveillance programs employed by aircraft maintenance facilities in the United States, including specific vision standards and tests used for inspection personnel. <b>METHODS:</b> We interviewed medical surveillance program personnel from nine major aircraft maintenance facilities and repair stations by phone or in person. The current vision standards for inspectors at each of the facilities surveyed were extracted from internal facility documents. Additionally, we reviewed the vision screening tests used for medical surveillance of inspection personnel. <b>RESULTS:</b> There were differences in the vision standards for near vision (Snellen 20/20 and 20/25, Jaeger #1 and #2, Ortho Rater #8) distant vision (20/25, 20/30, none), color vision (distinguish and differentiate contrast among colors, colors in the methods, normal color vision), and test intervals (annual, 2-year) at the facilities surveyed. Vision screening tests used in the medical surveillance programs at these facilities were equally diverse, including choice of vision screening instruments (Stereo Optical, Titmus), wall charts, reading cards, and pseudoisochromatic plate color vision screening tests. <b>CONCLUSION:</b> Medical surveillance programs for the aircraft maintenance facilities we surveyed differed considerably for both vision standards and screening tests used to evaluate vision performance of inspectors. The use of uniform vision standards and test methods would provide quality control and facilitate a more accurate evaluation of the visual capabilities for inspection personnel.</p>					
17. Key Words <p>Nondestructive Inspection; Nondestructive Testing; Visual Inspection; Aircraft Maintenance; Medical Surveillance</p>				18. Distribution Statement <p>Document is available to the public through the Defense Technical Information Center, Ft. Belvoir, VA 22060; and the National Technical Information Service, Springfield, VA 22161</p>	
19. Security Classif. (of this report) <p align="center">Unclassified</p>		20. Security Classif. (of this page) <p align="center">Unclassified</p>		21. No. of Pages <p align="center">14</p>	
				22. Price	



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# MEDICAL SURVEILLANCE PROGRAMS FOR AIRCRAFT MAINTENANCE PERSONNEL PERFORMING NONDESTRUCTIVE INSPECTION AND TESTING

## INTRODUCTION

Recurring visual and nondestructive inspection and testing (NDI/NDT) is crucial for ensuring that aircraft are maintained in safe operating condition. A recent FAA report, entitled "Analysis of Airworthiness Directives 1995 to 1999," indicated that 57% of all Airworthiness Directives issued during this period mandated some type of inspection. The report further states that 62% of these directives require visual inspection. In addition, a Federal Aviation Administration (FAA) Advisory Circular (AC 43-204), entitled "Visual Inspection for Aircraft," dated August 1997, states that over 80% of the inspections on large transport category aircraft are visual inspections. For smaller commuter transport and privately owned general aviation aircraft, this percentage is even greater. These statistics suggest that the visual performance of aircraft maintenance personnel has a great influence on aviation safety.

Visual inspection tasks are performed by qualified professionals who gain their expertise through rigorous training programs and often years of on-the-job experience in aircraft maintenance work. Visual inspectors must make judgments about the condition of aircraft and aircraft components, frequently using only their vision and basic visual aids (magnifiers, mirrors, and flashlights) to detect anomalies. NDI/NDT specialists are trained and often certified to use sophisticated imaging devices and techniques (fluorescent penetrant and magnetic particle inspections, ultrasonic scans, eddy current imaging, X-rays, etc.) to perform a variety of procedures developed to increase the probability of detecting subtle defects in aircraft parts and assemblies. While visual aids, imaging devices, and technical procedures can enhance their ability to identify defects, it is essential that these individuals possess good visual skills in order to carry out inspection tasks effectively.

In some aircraft maintenance facilities, visual inspectors and NDI/NDT specialists are considered separate and independent groups with differing skills and job qualifications. Other facilities, however, do not formally distinguish between these groups, as there is often considerable overlap in both the tasks they perform and the expertise required. The major difference between these workers is that visual inspectors normally inspect the assembled or

partially assembled aircraft, while NDI/NDT specialists tend to focus on the aircraft's individual components. (NOTE: Except when it is appropriate to do otherwise, this document will refer to visual inspectors and NDI/NDT specialists collectively as NDI/NDT personnel.)

Statistics show that about 50% of adults in the United States have difficulty seeing clearly at far distances, and about 60% have difficulty seeing at near distances when no corrective lenses are worn. Research with subjects using their usual refractive corrections has indicated that the prevalence of impaired distant and near vision can be as high as 30% and 40%, respectively (1). When optimal manifest refraction is performed and best-corrected visual acuity (BCVA) is provided, these numbers can be substantially reduced. This result underscores the importance of frequent vision examinations and the use of best possible refractive correction by NDI/NDT personnel. In the absence of a properly administered vision-screening program, it is possible that a substantial percentage of the NDI/NDT workforce would perform their duties with less than optimal vision.

Nondestructive testing frequently requires precise visual inspection under a variety of conditions. For example, penetrant inspections involve the use of visible red or fluorescent dye to highlight surface imperfections or defective aircraft parts. The intensities of visible background light and excitation ultraviolet radiation are verified with calibrated light meters to ensure viewing conditions are optimal. Magnetic particle inspection also uses visible and fluorescent inspection techniques, while radiography relies on the individual's ability to detect subtle differences in contrast either on film images or on a video monitor. Additionally, when direct observation is impossible it may be necessary to use remote viewing techniques such as mirrors, telescopes, borescopes, or fiber-optic cameras attached to video monitors. Lighting conditions can also influence the effectiveness of a visual inspection of a part. Normal visual inspection is typically performed in the range of 50 to 100 ft-candles, which is equivalent to normal office lighting while inspection of fine detail may require up to 200 ft-candles. Under such varied conditions, inadequate vision can reduce a worker's effectiveness, resulting in poorly executed inspections that could compromise aviation safety.

Unfortunately, there have been several instances where the failure to identify visually detectable corrosion, cracks, or inclusions were found to be the probable cause or a contributing factor in aviation accidents. The National Safety Transportation Board (NTSB; NTSB/AAR-98/01)(2) reported that on July 6, 1998, in Pensacola, Florida, two passengers died on Delta Flight 1288 during an aborted take-off attempt as a result of an uncontained engine failure. The cause was linked to a flawed maintenance inspection that failed to identify a detectable crack in the engine hub. Other reports that questioned the effectiveness of NDI/NDT inspections include the United Airlines crash at Sioux City, Iowa, on July 17, 1989 (NTBS/AAR-90/06)(3), and a rapid decompression event on Aloha Airlines Flight 243, near Maui, Hawaii, in April of 1988 (NTBS/AAR-89/03)(4). These accidents resulted in passenger and flight crew fatalities, as well as the loss of millions of dollars due to legal actions and lost revenue due to reduced public confidence in these airlines. Whether or not the poor visual performance of inspectors was specifically to blame in these instances may never be determined beyond a reasonable doubt; however, these events emphasize the importance of an effective medical surveillance program for NDI/NDT personnel that includes a suitably rigorous vision-screening process to keep their visual performance at optimal levels.

Although most aircraft maintenance personnel must meet minimum qualification standards upon initial employment and to become certified<sup>1</sup> for performing specific NDI/NDT procedures, the vision performance requirements observed at private, military, and commercial aircraft maintenance facilities lack standardization. Furthermore, there is currently no federal regulation that identifies specific occupation-based vision standards for these individuals. On September 26, 2001, in recognition of this general lack of national policy concerning qualification requirements for NDI/NDT personnel, the FAA's Production and Airworthiness Division (AIR-200) prepared a memorandum to address the issue (5). The memorandum recommended adopting minimum qualification and certification standards originally developed by several national and international organizations for NDI/NDT personnel. The standards identified in this memorandum were those found acceptable by the FAA for assuring that only qualified individuals perform NDI/NDT procedures (Table 1).

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<sup>1</sup>American Society of Nondestructive Testing, Inc. (ASNT), Recommended Practice No. SNT-TC-1A, defines *qualified* as "demonstrated skill, demonstrated knowledge, documented training and documented experience required for personnel to properly perform the duties of a specific job"; *certified* is defined as: "written testimony of qualification."

The FAA Aircraft Maintenance Division (AFS-300) and the Airworthiness TCRG (Technical Committee Research Group) recently recommended that the minimum vision performance standards adopted by industry be reviewed to determine if they are adequate for all tasks performed by NDI/NDT personnel and, if necessary, research be performed to aid in the development of a task-based vision standard. In support of this research effort, multiple studies were performed to analyze the demographic characteristics (6) and vision-task requirements of NDI/NDT and visual inspectors (7). The results of these studies will be provided in separate reports. The present report identifies the medical surveillance programs utilized at selected aircraft maintenance facilities in the United States and determines how these facilities currently perform the vision testing necessary to verify the ocular status of their employees.

## METHODS

A research protocol was developed to assess the visual performance demands placed on workers performing maintenance inspections. Due to resource limitations, this initial investigation identified the visual performance requirements of three specific inspection procedures. These procedures included fluorescent penetrant, borescope, and visual inspection. Personnel and facility surveys were conducted, visual-task data were collected, and reviews of medical surveillance programs for inspection personnel were performed at five commercial airline maintenance facilities, two private aircraft repair stations, and one military aircraft repair facility. We analyzed the vision standards currently applied to NDI/NDT personnel and the vision screening tests used at these facilities to confirm that workers meet the level of vision performance required by these standards.

## RESULTS

The vision standards at the maintenance facilities surveyed are presented in Table 2, including near vision, distant vision, color vision requirements, and the interval for testing used by each facility. (Note: The names of the maintenance facilities are withheld for the sake of anonymity and letter identifiers were assigned.)

Table 3 summarizes the actual vision tests used for medical surveillance of NDI/NDT personnel at the facilities surveyed.

**Table 1: FAA Recommended Vision Standard for NDI/NDT Personnel**

<b>VISION STANDARD</b>	<b>NEAR VISION</b>	<b>DISTANCE VISION</b>	<b>COLOR</b>	<b>INTERVAL</b>
MIL-STD-401E	Jaeger #1 at not less than 12" or equivalent with one eye, either natural or corrected.	None.	Distinguish and differentiate between colors used in the method for which certification is sought (Practical alternative).	Annual
ATA Specification 105	Snellen 20/25 or Jaeger #2 in at least one eye. Vision required from both eyes.	Snellen 20/50 in at least one eye. Vision required from both eyes.	Distinguish and differentiate between colors used in the method.	Not to exceed two years.
AIA NAS 410 (May 1996)	Jaeger #1 test chart at not less than 12" or equivalent as determined by medical personnel with one eye, either natural or corrected.	None.	Distinguish and differentiate between colors used in the method for which certification is sought.	Near vision annually and color perception tests shall be administered prior to certification or recertification
ISO 9712 (1999-05-01)	Reading a minimum of Jaeger #1 or Time Roman N4.5 or equivalent letters at not less than 30cm with one or both eyes, either corrected or uncorrected.	None.	The candidate can distinguish and differentiate contrast between the colours used in the NDT method concerned as specified by the employer.	Annual

<b>Facility</b>	<b>Near Vision</b>	<b>Distant Vision</b>	<b>Color</b>	<b>Interval</b>
(A)	Near Vision, of at least one eye, either corrected or uncorrected, must be such that the employee can read SNELLEN equivalent of 20/25 (Jaeger #2 or Ortho-Rater #8).	Distant vision, of at least one eye, either corrected or uncorrected, must be equal to or better than SNELLEN equivalent of 20/30	Color perception will be measured by the HRR Pseudo-Isochromatic Screening series or Ishihara Color Vision Tests. Any deficiencies are subject to approval of the Medical and NDT departments.	2 years
(B)	Near Vision of at least one eye, either corrected or uncorrected, must be such that the inspector can read Snellen equivalent of 20/25 (Jaeger #2 or Ortho-rater #8).	Distant vision of at least one eye, either corrected or uncorrected, must be equal to or better than Snellen equivalent 20/30	Color vision shall be considered along with any physical requirements for inspection personnel at facility B.	2 years
(C)	The applicant must be capable of reading a minimum of Jaeger Number 2 letters at a distance of 12” on the standard Jaeger Test Chart, or equivalent, in at least one eye, either corrected or uncorrected. Must be such that the employee can read SNELLEN equivalent of 20/25.	Distant Vision, of at least one eye, to better than SNELLEN equivalent of 20/30.	Color vision will be checked to determine any deficiencies that applicant has when performing MT or PT.	2 years
(D)	Near vision of at least one eye, either corrected or uncorrected, must be such that the individual can read Snellen equivalent of 20/25 or Ortho-Rater #8 (Jaeger #1 @ 12” for NDI Inspectors) (Jaeger 2 @ 12 inches for visual inspectors)	Distant Vision of at least one eye, either corrected or uncorrected, must be equal to or better than Snellen equivalent of 20/30.	Color contrast differentiation - capable of distinguishing and differentiating contrast among colors.	Yearly
(E)	Near Vision – An annual examination by a medical technician using Snellen equivalent of 20/25 or Jaeger #1 @ 12 “ or equivalent, may be corrected	None	Color perception – Shall be given to all NDI technicians at the same time as vision examination. Must be able to distinguish and differentiate between colors using the method for certification sought	Annual
(F)	Near Vision - Jaeger #1 test chart at not less than 12 “ or equivalent in with one eye, either natural or corrected.	None	Color Perception: Distinguish and differentiate between the colors used the method for which certification sought	Annual
(G)	Natural or corrected near distant such that the individual is capable of reading with at least one eye, the Snellen equivalent of 20/25. (Ability to perceive Ortho-Rater minimum of eight or similar test pattern is also acceptable)	None	Individual shall be capable of distinguishing contrast between colors using Ishihara color plates or another method which gives equivalent results.	2 years
(H)	Visual acuity (natural or corrected vision required to the following standard in at least one eye) Near Vision 20/20 Snellen equivalent required.	Visual acuity (natural or corrected vision required to the following standard in at least one eye) Near Vision 20/25 Snellen required standard.	Color Perception - Normal color vision is required for inspection personnel assigned to an inspection process in which color differentiation is essential.	2 years



**Table 3: Vision Screening Methods Used by Selected Maintenance Facilities**

Facility	Near Vision Test Used	Distant Vision Test Used	Color Test Used	Test Performed By
(A)	Stereo Optical Vision Tester	Stereo Optical Vision Tester	Stereo Optical Vision Tester and/or Ishihara PIP	On-site Medical Personnel
(B)	Stereo Optical Vision Tester	Stereo Optical Vision Tester	Stereo Optical Vision Tester	On-site Medical Personnel
(C)	EPSDT near Snellen card	Snellen Wall Chart	Ishihara (Concise Ed.)	On-site Non-medical Personnel
(D) Site 1	Titmus Vision Tester and/or Western Optical Reading Card	Titmus Vision Tester	Titmus Vision Tester and/or Good-Lite PIP	On-site Medical Personnel
(D) Site 2	Western Optical Reading Card	Snellen Wall Chart	Good-Lite PIP	
(E)	Titmus Vision Tester	N/A	Dvorine PIP	Off-site Occupational Medicine Personnel
(F)	Graham-Field Jaeger Reading Card	N/A	Richmond International Pseudoisochromatic Plate Test	On-site Occupational Medicine Personnel
(G)	Titmus Vision Tester	N/A	Titmus Vision Tester	On-site Occupational Medicine Personnel
(H)	Stereo Optical Vision Tester	Stereo Optical Vision Tester	Stereo Optical Vision Tester and/or Ishihara PIP	On-site Medical Personnel

## DISCUSSION

Administrative differences in medical surveillance programs and the latitude allowed by the recommended vision standards resulted in considerable variation in vision screening methodology among the facilities surveyed. For example, larger maintenance facilities are more likely to have on-site clinics with medical personnel on staff to provide emergency and routine medical support for a substantial number of workers. Repair stations employ a considerably smaller workforce and may provide a medical professional (full or part-time), arrange periodic visits from local occupational healthcare providers, or contract their medical surveillance needs with off-site clinics.

An aircraft maintenance worker's job classification and vision performance requirements can vary within certain limits, and oversight is dependent on the administrative policy of the employer. At some facilities, NDI/NDT operations are kept independent of visual inspection activities, allowing for clearly defined job titles, responsibilities, and vision performance requirements between NDI/NDT specialists and visual inspectors. In these facilities, NDI/NDT specialists may be allowed to perform most visual inspection tasks, but not all visual inspectors are qualified to perform certain NDI/NDT procedures due

to training and certification requirements associated with these tasks. In other maintenance facilities, NDI/NDT specialists and visual inspectors were combined into a single department under a common administrative staff with identical medical surveillance practices. When this structure is applied, vision performance requirements must logically default to the most stringent standard required for any inspection task performed at the facility. However, even when two facilities perform similar maintenance tasks and apply similar administration policies, minimum vision performance requirements and vision screening tests can vary, depending on the particular recommended standard adopted by the facilities.

Work-related specifications often dictate the type of inspection or test required for a particular aircraft and/or aircraft component. These specifications also impact the qualification and certification requirements of the individual performing the work. The certification process often requires the worker to meet a specific vision standard. In other words, depending on the type of work being performed, an employee's vision requirements are more closely associated with the individual's qualification and certification requirements than his specific job title (NDI/NDT specialist or visual inspector).

Vision screening is further complicated due to multiple specifications for minimum visual acuity requirements used to certify NDI/NDT specialists who perform particular procedures. For example:

*NAS 410* (1996) recommends: "Near Vision - Jaeger #1 test chart at not less than 12 inches or equivalent visual examination as determined by medical personnel."

*SNT-TC-1A* recommends: "Jaeger Number 2 or equivalent type and size letter at the distance designated on the chart but not less than 12 inches (30.5 cm) on a standard Jaeger test chart."

Jaeger or similar test cards are used mainly to determine whether an individual has adequate accommodative ability or whether the near addition in spectacles (i.e., the bifocal addition) is sufficient for older individuals (Figure 1). The earliest reading test cards to attain widespread popularity were introduced by Jaeger in 1854 and are still in use. Print sizes are numbered for reference with the prefix J (i.e., Jaeger number), the smallest size being J1. Each progressively larger text is noted with an increase in the J number. In some references, J1 is reportedly equivalent to 20/15 optotype and J2 to 20/20 optotype. However, tests are often implemented inconsistently

with different cards and no specified test distance (8). Originally, the "Jaeger number" simply referred to the number on the boxes in the print shop from where Jaeger selected his type; therefore, the number had no corresponding biological or optical foundation (8). Jaeger values have undergone a number of revisions over the years, but the "Revised Jaeger Standard" was adopted in the late 1950s (9). The Revised Jaeger Standard recommends that all near testing be kept at 14 inches. At this distance, J1 is equivalent to 20/20 Snellen visual acuity (10). Moving a chart closer or further away than the recommended testing distances changes the visual angle of the optotypes, resulting in changes to the visual acuity required to read the chart. If the Revised Jaeger Standard is used but the testing distance is changed, as has been recommended in some of the NDI/NDT vision standards, the actual visual acuity measured will vary. For instance, when the Revised Jaeger Standard is used, for J1 to be equivalent to 20/15 and J2 equivalent to 20/20, the test must be performed at a distance of 17.5 inches. For someone with presbyopia, reading a near vision chart is easier at greater distances because there is less accommodative demand.

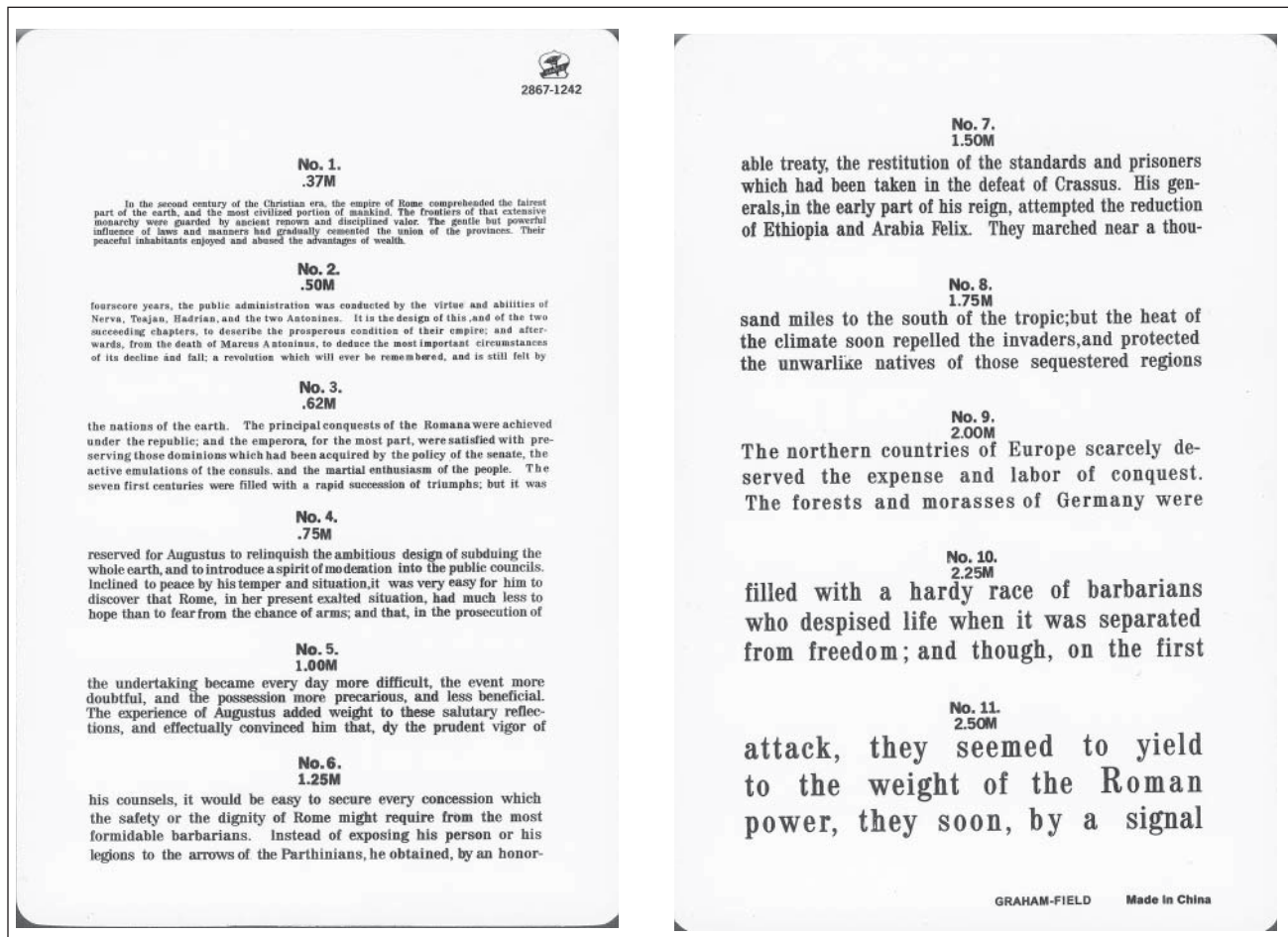


Figure 1. Jaeger Near Vision Card

Unfortunately, the actual visual acuity measured with Jaeger cards can vary even when the recommended 14-inch test distance is maintained. Depending on the manufacturer, the size of print (point size) on Jaeger cards may vary by half a point. Therefore, J1 can be 3 to 4 point, or 20/20 to 20/25 Snellen acuity at a 14-inch (35 cm) test distance, while J2 can be 4 to 5 point, or 20/25 to 20/32 Snellen acuity at the same test distance (8). As a result of this inconsistency, it is suggested that reduced Snellen visual acuity charts be adopted for near vision tests should modifications be made to the current recommended vision standards.

In addition to differences in the devices used to conduct vision screening, the way they were administered also varied among facilities. Vision standards at most of the surveyed facilities required that inspectors meet the minimum acuity requirement in at least one eye (corrected or uncorrected). Only Facility D tested all inspectors' binocular vision function as well as each eye independently. Eyecare practitioners routinely measure visual acuity in each eye, separately, as this practice can detect small changes in refractive error and may indicate functional changes in the visual pathway that can result from a pathological condition. However, if a person is monocular (i.e., < 20/200 in poorer eye), binocular acuity will be equal to that of the eye with better vision. For a binocular person, the binocular measurement is usually one-half to two lines of optotype better than that of the eye with better vision. Since most workers are binocular, a binocular measurement of visual acuity may better predict a person's functional capability in the workplace. However, measurement of monocular acuities should also be encouraged to better detect pathological and functional changes in vision.

As this study shows, a number of tests are currently used to measure visual acuity at near distances. Jaeger cards were the most commonly used testing device for near vision by the facilities surveyed. As previously mentioned, depending on the manufacturer, Jaeger cards may vary in print size. The Rosenbaum near vision testing card is another widely used card, but some versions have been shown to be inaccurate because the optotypes are not properly scaled to the Snellen system (i.e., Rosenbaum optotype is 38-62% larger) (11,12). Other testing methods included reduced Snellen charts and vision screeners such as the Stereo Optical and Titmus units. While all of these test methods are considered acceptable when properly administered, problems can arise when one method is used for near vision tests and another is used for distance. When testing a presbyopic person, the test card is often kept at the distance where the person's corrective lenses make the image clearest, not at the specific distance required for proper test chart calibration. Automated vision testers, such as the Titmus or Stereo Optical vision testers (Figure 2), should be carefully maintained (e.g., optics and slides kept clean, change bulb periodically) and require some degree of training to be used effectively. Inaccurate findings may result when using these instruments if the person administering the test has not had adequate training and does not perform testing correctly (13,14). Vision testers are designed to be tabletop instruments that optically simulate a test distance of 14 inches for near tests and 20 feet for distant tests. The actual nearness of the test slides, however, can stimulate an unintentional convergence of the eyes by the observer (proximal convergence) leading to less reliable findings (15).



**Figure 2.** Stereo Optical (L) and Titmus (R) Vision Testers

As a result of these difficulties, use of a reduced Snellen visual acuity card (Figure 3), similar to the Near Vision Acuity chart (FAA Form 8500-1) used by the Federal Aviation Administration, should be encouraged. The card should be held at 16" (40 cm) from the eyes, at right angles to the line of sight, and illuminated with not less than 10 nor more than 25 foot-candles of light. The automated vision testers, such as the Titmus or Stereo Optical vision testers, are acceptable alternatives as long as testing is performed as instructed by the manufacturer and by properly trained personnel.

Observations of inspectors on-the-job have found that a substantial percentage of time is dedicated to work at intermediate distances (20-30") (7) and the average age of the workforce is 45 years (6). Because an inspection item

may not be accessible at the inspector's prescribed best-corrected near visual acuity distance, an intermediate vision test may be necessary to assess a presbyopic individual's visual performance capabilities more accurately. The current FAA aeromedical standard for first- and second-class pilots 50-years of age or older is 20/40 at 32" (16). A similar age-specific intermediate vision standard may be appropriate for NDI/NDT personnel (7).

Distant visual acuity is not required by all the standards recommended by the FAA. However, when distance acuity is included as a requirement at a particular maintenance facility, the required visual acuity ranged from 20/20 to 20/50 (5). Visual acuity at distance is most often measured with high contrast letter charts, and there are numerous charts available that can be used at different testing

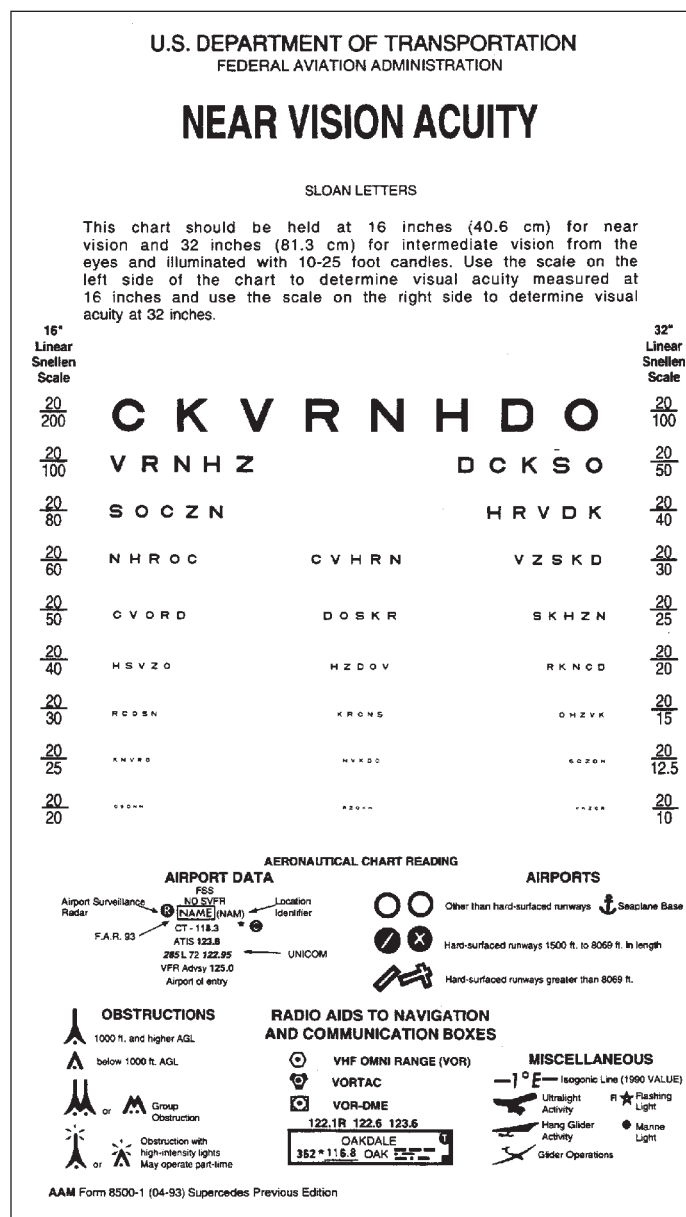


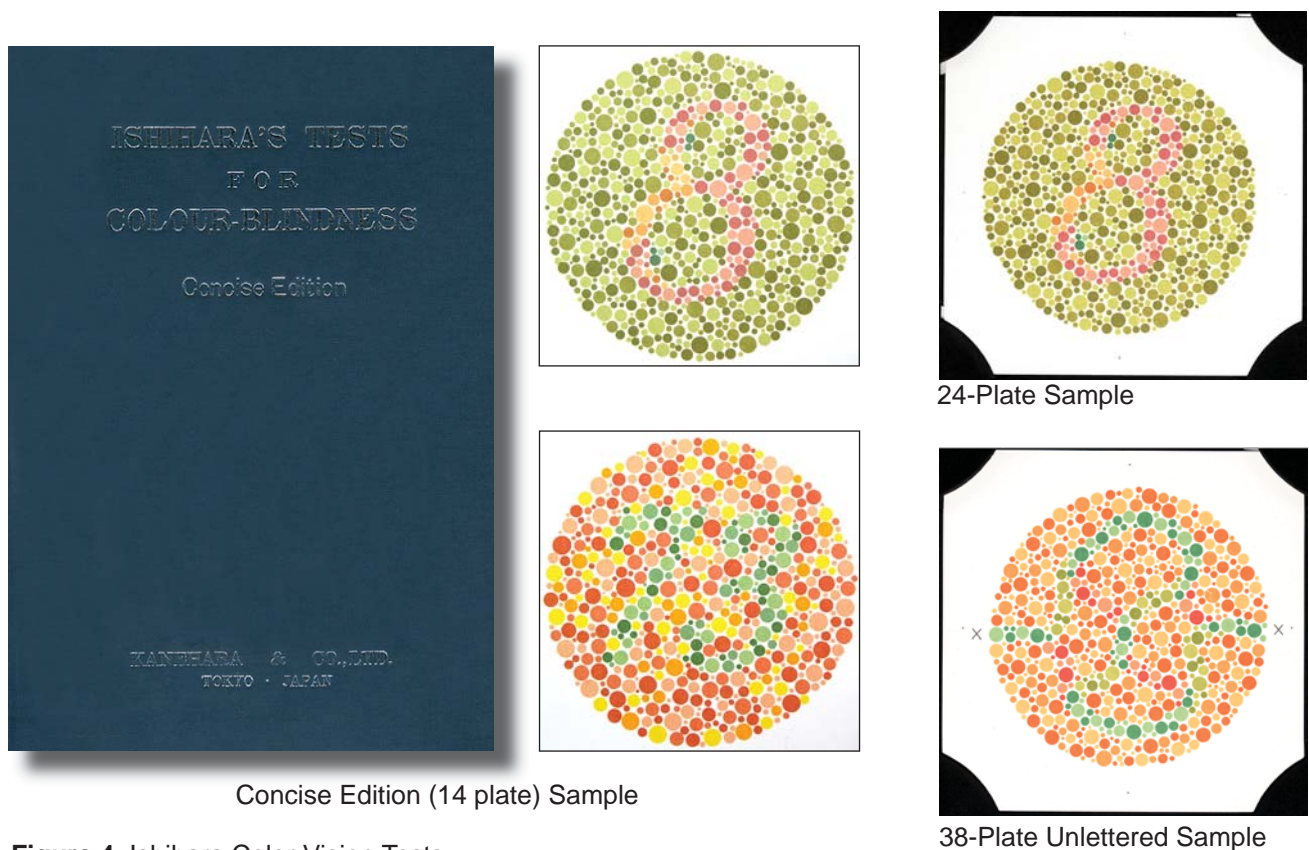
Figure 3. Near Vision Acuity Chart (FAA Form 8500-1)



distances. The present international recommendation for distance visual acuity testing is based on a measurement of 4 m (13 ft), because a 6 m (20 ft) distance is not always possible in some examining rooms. In addition, to be comparable with the distance visual acuity, it is more desirable to measure near visual acuity with the same test symbols or optotypes as used for visual acuity at distance. Finally, the luminance level use for the test affects visual acuity values and, therefore, standardization is important. For standardization of test results, a Snellen 20-foot eye chart or equivalent vision-screening device is recommended for testing NDI/NDT personnel. The chart should be placed 20 feet from the applicant's eyes and the 20/20 line should be placed at approximately eye level. The eye chart should be illuminated by a 100-watt incandescent lamp placed 4 feet in front of and slightly above the chart. Care should be taken to prevent direct or reflected glare from interfering with the applicant's view of the chart. The examination room should be darkened, with the exception of the illuminated chart.

The color vision standards recommended for aircraft maintenance personnel often only require the ability to distinguish and differentiate colors used in specific testing or inspection tasks. Some facilities surveyed used sophisticated color vision tests, while others used modified versions of these tests. It is often stipulated that practical tests be

employed should an individual fail the initial color vision test. The myriad of possible variations in practical color vision tests effectively eliminates the potential for any standardization. However, when optimal color perception is required, the most commonly used color vision screening tests in optometric clinics are the American Optical (AO) or the Ishihara pseudoisochromatic plates with numbers. Many different tests have been produced containing similar designs to the Ishihara plates; however, the color quality often varies and none are superior to Ishihara for color vision screening (17). At some facilities, the "Ishihara Concise Edition," introduced in 1989, was being used. However, it has been reported to be less accurate than the Ishihara 24- or 38-plate series (17). The Concise Edition's 14 test plates differ from the other Ishihara test plates in that they are printed on white background instead of individual white cards interleaved onto a black surround, as illustrated in Figure 4 (18). Additionally, the size of the color difference step determines the level of difficulty for the test. If this is inappropriate, either false positives or false negatives will result. If the color difference step is too small, someone who has normal color vision may be incorrectly diagnosed as color deficient, or if the color step is too large, some color deficient observers may be incorrectly classified as normal trichromats (18). Individuals who fail the pseudoisochromatic plate test may need to



**Figure 4.** Ishihara Color Vision Tests

be quantitatively assessed by using a functional test such as the Farnsworth Panel D-15 test (Figure 5). In this test, the person arranges colored caps in order starting with a blue “pilot” cap so that the next cap is closest in color with the previous. The advantage of this test is that the patient cannot memorize the test, as the caps are mixed, making each test situation new. The test reveals both the axis of the color deficiency, whether red-green or blue-yellow, and the severity of the deficiency.

Regardless of the color vision test used, testing conditions are critical for the validity of the tests. When non-standard illumination is used, those with color deficiencies may pass tests they would ordinarily fail, and those with normal color vision may fail tests they would ordinarily pass (19). Illumination should closely approximate northern skylight in natural daylight (19). It is recommended that all measurements of color vision be done under a day light lamp with a color temperature close to 6774K, the Commission Illumination de E' Clairage (CIE) standard illuminant. Currently, the Richmond True Daylight HRR Illuminator with an easel stand meets CIE illumination standards for color vision testing.

In summary, it is evident from this review that the vision standards and medical surveillance practices vary greatly at different aircraft maintenance facilities. Even when the vision standard used had similar performance requirements (near and distance acuity, color vision), the method of application (who is tested) and administration (who performs the tests) differed, as did the method used for validation (vision screening test performed). Other differences included the time interval between examinations, the location for testing, and whether the tests are performed binocularly or monocularly. A review of the existing vision screening tests at other maintenance facilities may be necessary so that a meaningful spectrum of tests can be recommended that will effectively



**Figure 5.** Farnsworth D-15

characterize an inspector's vision as adequate for the tasks performed. Use of standardized tests would also provide better quality control and a more accurate evaluation of visual capabilities for inspection personnel. Practical application of vision testing can improve the reliability and effectiveness of many inspection tasks and enhance aviation safety.

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